

1980

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Waltz, J. C. and Soedel, W., "On the Development of a Reed Valve Impact Fatigue Tester" (1980). *International Compressor Engineering Conference*. Paper 365.

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ON THE DEVELOPMENT OF A REED
VALVE IMPACT FATIGUE TESTER

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ABSTRACT

This paper discusses experiences with the development of a high speed valve impact fatigue tester, following the development of a similar earlier tester by Svenzon[1]. New features are direct impact velocity measurements and an acoustic enclosure-muffler design.

INTRODUCTION

This paper presents some contributions to the development of high frequency impact fatigue testers for compressor reeds. The first tester of the kind discussed here was developed by Svenzon [1] at the Sandvik Research Center. The impact fatigue tester discussed in this paper follows in many of its essential features this Sandvik Impact Fatigue Tester. However, some of the deviations that were made are of general interest.

Impact fatigue is one of the principal modes of reed valve failure; it is "characterized" by crack development at the periphery of the reed in the vicinity of the seat. The other principal failure mode is bending failure. Definitions of these failure modes are given in reference [2].

OPERATING PRINCIPLE

It is difficult to excite a valve reed at high frequencies (usually at approximately the first natural frequency, which is considerably higher than the operating frequency in the compressor) by a gas jet that is periodically interrupted by a rotating perforated disk, because it takes too much time for the flow to develop again after it has been cut off. Recognizing this, a fluidic flip-flop circuit has to be used, as shown in Fig. 1 and first applied by Svenzon [1]. In this case the main flow is never interrupted, but rather redirected from one flow channel to the other. The two channels which are excited in this manner are shown at the top of the figure. A pulsating control flow created

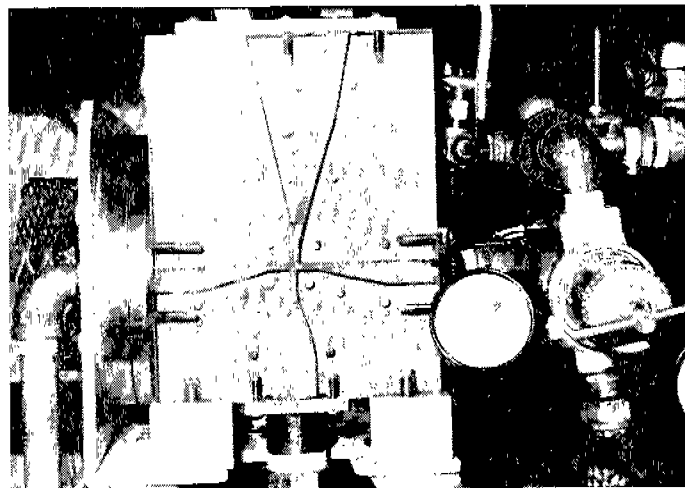


Fig. 1 Fluidic Flip-Flop Circuit

by a rotary valve and coming from the left in the figure causes the switching of the primary flow. The relatively weak control flow is much less affected by interruptions than is the main flow. The two flow channels are directed against the valve reed as shown in Fig. 2.

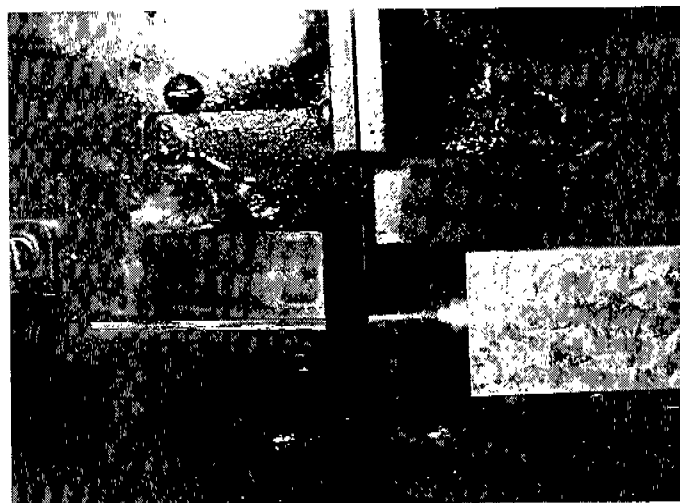


Fig. 2 Dual Flow Channel Drive of Reed Valve

The valve seat that is impacted on by the valve reed is part of a massive rod that is floating on an air bearing. The rod is prevented from moving away from the impact as a rigid body by a weak spring, which in this case is a rubber O-ring that braces the rod against the foundation. The seat-rod assembly is shown in Fig. 3.

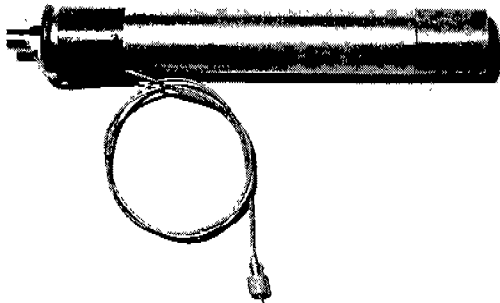


Fig. 3 Seat-Rod Assembly with Accelerometer

So far, the discussed features of the Impact Fatigue Tester are practically identical to those developed by Svenzon [1].

MEASUREMENT OF IMPACT INTENSITY BY ACCELEROMETER

The experimental investigations by Svenzon [1,3] have used the magnitude of the acceleration pulse created in the rod by impact of the reed valve against the seat to determine the intensity of the impact. The magnitude of the acceleration pulse was measured by an accelerometer mounted on the rod face opposite the seat. The mounting arrangement can be seen in Fig. 3. The magnitude of the accelerometer signal was calibrated to the change in momentum of a steel ball dropped on the valve seat. The change in momentum of the steel ball defined a reference impact intensity against which the intensity of the reed valve impact was measured.

On the impact fatigue tester discussed here, measurements agreed in character with those reported by Svenzon and are typically as shown in Fig. 4. The observed oscillation corresponds to the repeated passing of the acceleration wave, which is a function of the speed of sound of the seat rod material and the length of the rod. In this case this frequency is approximately 20,000 Hz. With each passage, energy

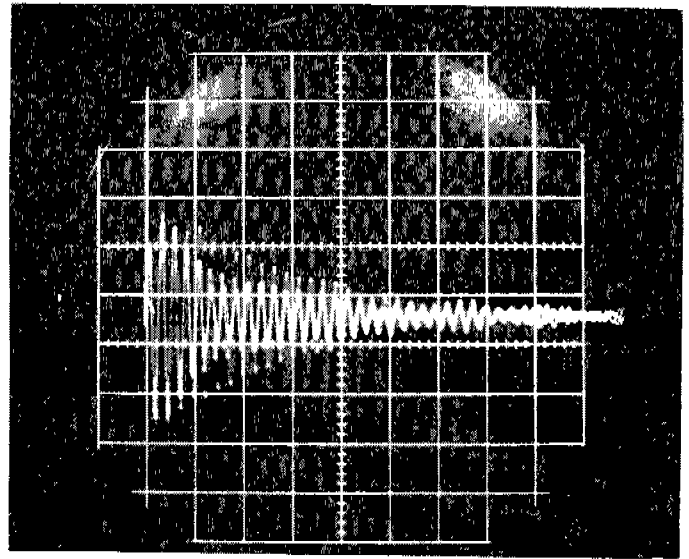


Fig. 4 Accelerometer Signal

is dissipated into heat and the signal decays, until the next impact takes place, in this case at a frequency of approximately 125 Hz.

Standardization of this method and its calibration will probably be the primary difficulty in its acceptance.

DIRECT DISPLACEMENT OR VELOCITY MEASUREMENTS

From a theoretical model that uses plane wave approximations, it can be shown [2,4] that the magnitudes of the impact stress pulse created in the valve reed through its thickness and in the seat are only a function of the impact velocity and material properties, and not of the thickness of the valve. This indicates that for pure impact, it is the velocity that is important and not the impact intensity or momentum conversion. For example, a valve of thickness h and impact velocity v will have the same stress wave magnitude in its seat contact area as a valve of twice the thickness, $2h$, as long as its impact velocity v is the same. The reason is that during impact the valve has to be considered to be elastic through its thickness and not inelastic. While this reasoning holds only for pure impact and becomes obscured when waves normal to the reed surface and bending waves parallel to the reed surface becomes mixed it still indicates that impact velocity is the more fundamental parameter and not impact intensity.

It was, therefore, decided to develop a way to measure impact velocity. For this purpose the seat-rod assembly was modified to accept in the seat an inductive transducer, following previous approaches where valve motion was measured in the compressor. The seat with the inductive

transducer face is shown in Fig. 5.

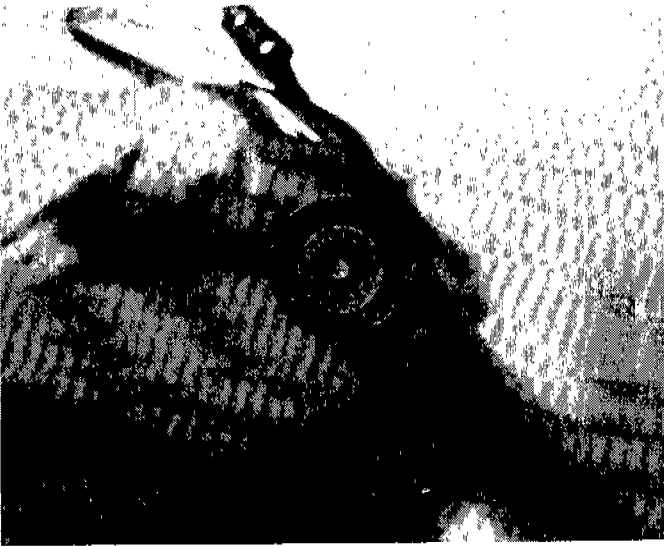


Fig. 5 Seat with Inductive Transducer

The grey ring area is the induction coil. As the distance between the transducer surface and the valve reed increases, the magnetic field that is created changes. The linear range of this type of arrangement is limited, it is linear in the vicinity of the seat. This is fortunate because this region is where one has to determine the displacement of the reed as function of time accurately, since the time derivative in this region is the required impact velocity.

Fig. 6 shows a typical displacement-time trace, as obtained from a digital storage oscilloscope. The slope is the impact velocity and can be obtained with accuracy. The roundedness of the trace in the small displacement vicinity stems from the fact that the reed is deflecting into the seat interior due to its momentum at contact. The change in seat position indicates that the seat is not motionless. Fig. 7 shows this seat motion more clearly and a certain periodicity of motion can be observed. This period corresponds to the natural frequency of the seat-rod assembly on its retaining spring (the O-ring), which is approximately 25 Hz. This does not cause any principle difficulty, as long as it is much less than the impact frequency.

It is, of course, of advantage to eliminate the graphical determination of impact velocity. For this purpose a differentiating circuit can be used. A typical output is shown in Fig. 8. Time increases from left to right. The top trace is the displacement signal while the bottom trace represents velocity. Care has to be taken that the frequency response of the differentiating circuit is high enough so that all important harmonics of the impact frequency, which

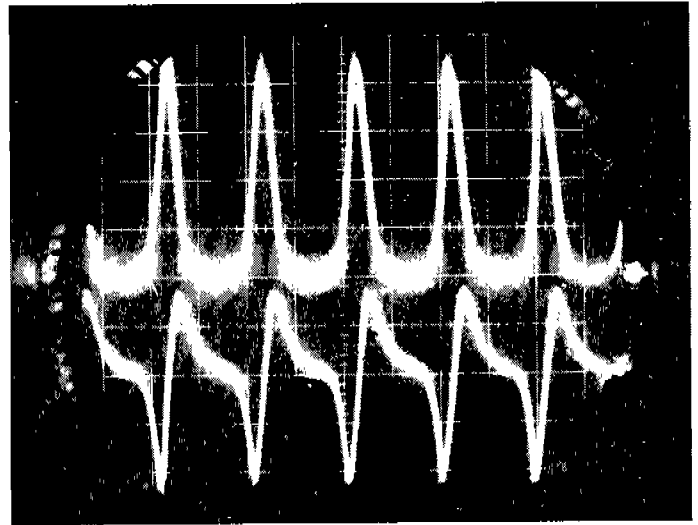


Fig. 8 Reed Valve Displacement and Velocity versus Time

contribute to the formation of the relatively sharp spike, so to speak, are properly differentiated.

ACOUSTIC ENCLOSURE-MUFFLER COMBINATION

The periodic gas discharges of the impact fatigue tester produce a noise level that is unsafe even for short exposure times without ear mufflers. Measured from the valve reed, at a horizontal distance of approximately 0.7 m and a vertical distance of approximately 0.8m., a typical sound pressure level for the experiment is 112 dBA. By designing a plexiglas enclosure around the experiment which does not interfere with visual observation, as shown in Fig. 9, and at the same time tuning the enclosure exhaust pipe (not visible in Fig. 9, it extends straight down into the table) such that the total enclosure design behaves as a low pass filter muffler [4], it was possible to reduce the sound pressure level from 112 dBA to 96 dBA.

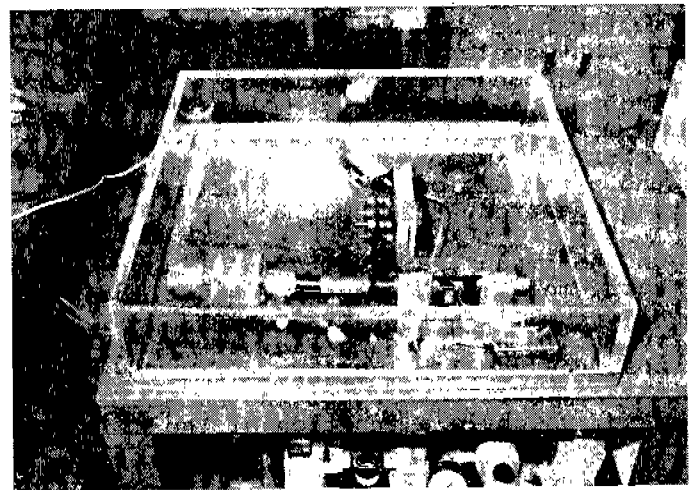


Fig. 9 Acoustic Enclosure and Muffler

This was a significant reduction and reduced the subjectively evaluated loudness dramatically. It should be noted that the enclosure served also as the muffler expansion chamber which is a more integral design than the perhaps more conventional approach; attaching to an enclosure an exhaust muffler.

SUMMARY

While developing an impact fatigue tester for reed valves, following largely the approach taken by Svenzon [1], certain deviations from Svenzon's design were judged to qualify as possible improvements and, therefore, to be of general interest. The improvements made were direct reed displacement and velocity measurements and the development of an enclosure-exhaust muffler.

ACKNOWLEDGEMENT

This paper is a product of a larger investigation into the impact stress and fatigue behavior of high speed compressor reed valves which is sponsored by the Copeland Corporation. This support is gratefully acknowledged. The technical assistance from the Sandvik Research Center, especially by Mr. Gerhard Persson, was and still is

very much appreciated. Thanks also go to Dr. J.P. Elson from the Copeland Corporation for his critical advice.

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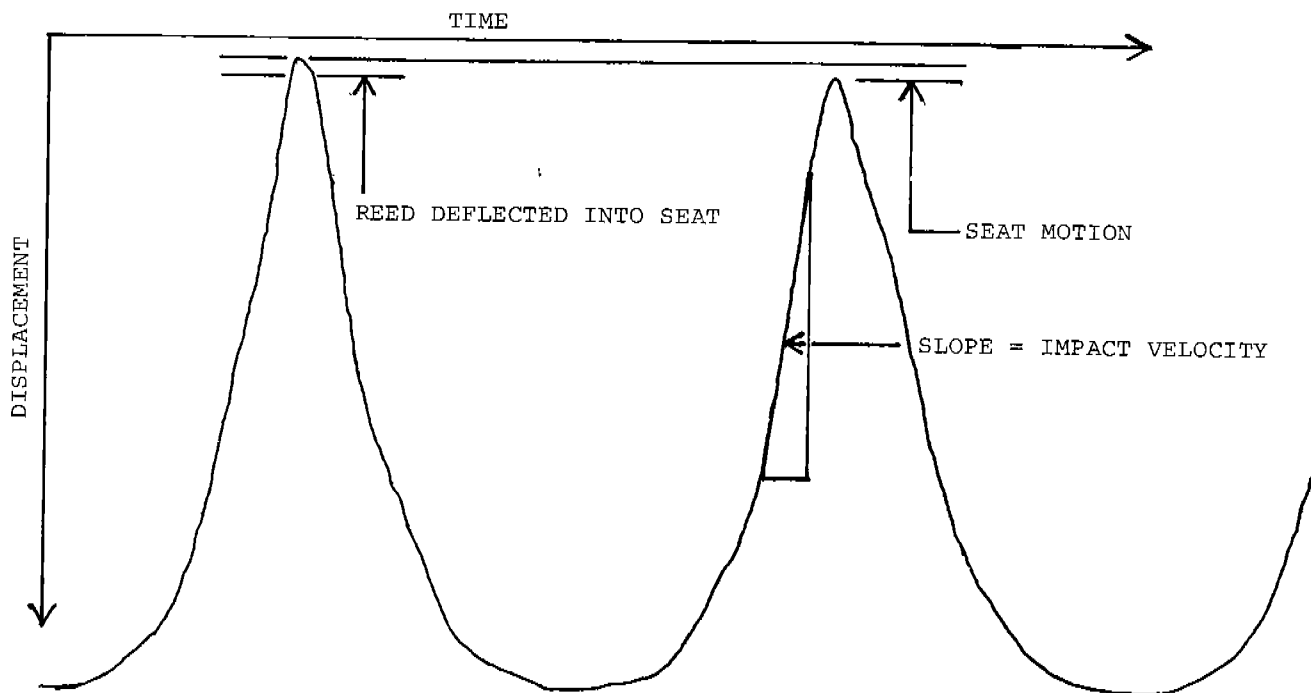


Fig. 6 Reed Valve Displacement versus Time

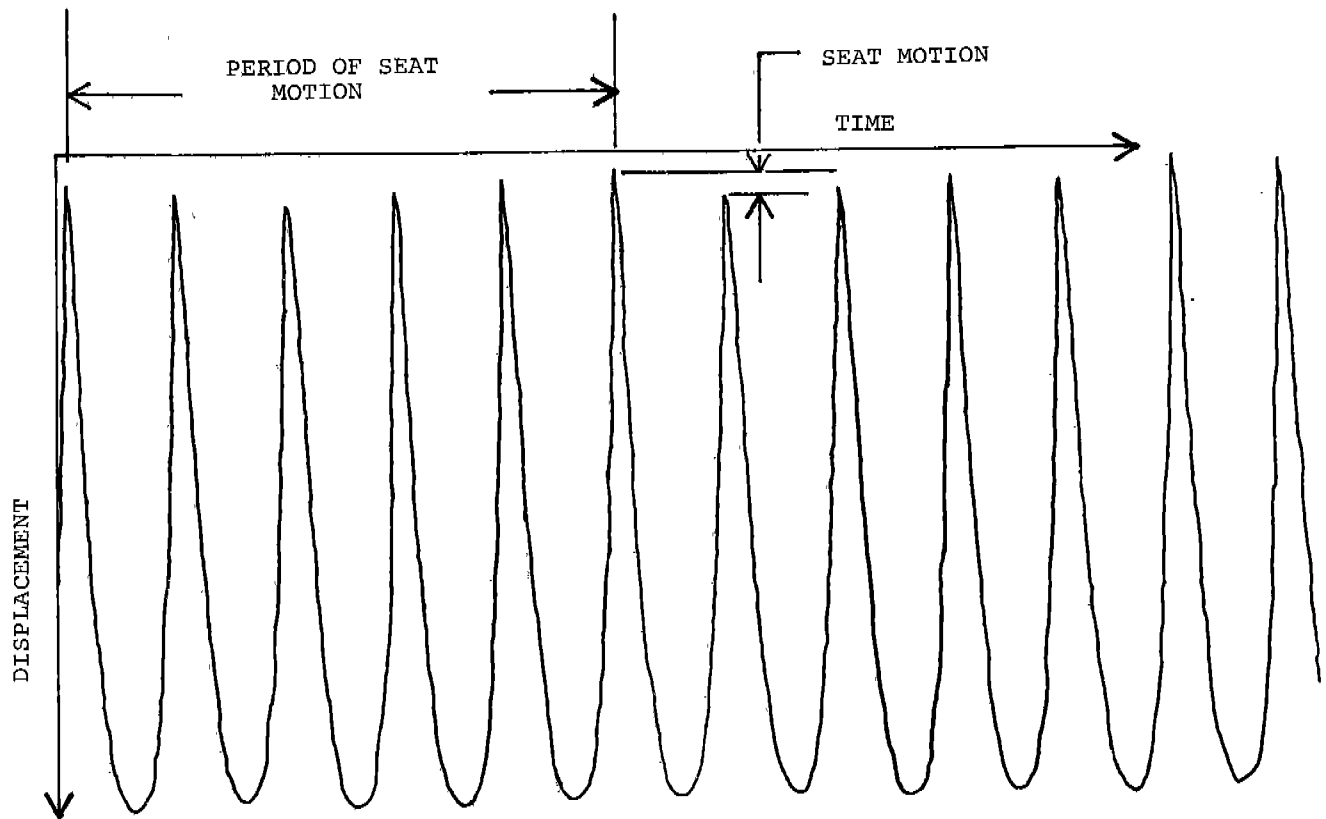


Fig. 7 Reed Valve Displacement versus Time